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DIAGNOSTICS OF THE DEFORMATION RESISTANCE OF THE TRACK BED IN THE INTER - STATION SECTION PALÁRIKOVO - NOVÉ ZÁMKY - TRACK NO. 1

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Abstract

The fundamental pillars of the emerging European integrated railway area include improving the safety of rail transport and the quality parameters of railway lines and ensuring their interoperability. As rail transport is one of the safest transport systems and the most environmentally friendly, the Slovak Railways (ŽSR) have developed strategic and investment plans to increase the competitiveness of rail transport in relation to other modes of transport. The current modernisation or reconstruction in the territory of the Slovak Republic focuses on the main railway lines that are part of significant European corridors (AGC, AGTC, TEN-T corridors). The inter-station section Palárikovo - Nové Zámky, the subject of the article, is a part of the European corridor No. IV, connecting Dresden with Arad and leading through the territory of the Slovak Republic. In this context, the article presents the analysis of the values of deformation characteristics on the reconstructed inter-station section Palárikovo - Nové Zámky, obtained verifying the quality of the implemented individual structural lavers of the track bed.

Keywords:

Railway track;
Line modernisation;
Track bed;
Deformation resistance;
Static modulus of deformation.

1 Introduction

The inter-station section Palárikovo - Nové Zámky is a part of the Pan-European Transport Corridor No. IV. In the territory of the Slovak Republic, it runs from the state border of the Czech Republic/Slovak Republic through Kuty, Bratislava and Štúrovo to the border of the Slovak Republic/Hungarian Republic, while the line length in the Slovak territory Republic is approx. 149 km. The respective corridor line continues to Budapest or connects Dresden, Germany, with Arad, Romania.

Considerations for the construction of a link between Vienna and Budapest, with a possible continuation to the Black Sea, were motivated in the past by Hungary's export interests. In 1844, the Hungarian Central Railway Company decided to build a left-bank route, thus concluding a long-standing struggle over the concept of a route along the left or right bank of the Danube. This decision eliminated the construction of a large bridge across the Danube, but many smaller rivers and streams flowing into the Danube had to be bridged. The Bratislava - Štúrovo or Budapest - Wien railway line was put into operation on 16 December 1850 and is one of the most significant sections of the Slovak railway network. This line also has been one of the oldest and most important lines in Europe as well as in the Austro-Hungarian Empire, as it connected the two most important cities of the monarchy - Budapest and Vienna - still important metropolises of Central Europe today.

Construction work on the line in question was started by the Magyar Középponti Vasúttársaság in 1844, and the Hungarian section Budapest-Vacov was put into operation in 1846. It was the first 33 km long steam railway line in Hungary. The Vacov - Štúrovo line was built only after the Hungarian Revolution in 1848. Later, a link from Marchegg to Bratislava was developed, creating a continuous steam railway between the metropolises of Austria-Hungary, namely between Budapest and Wien. The construction of the railway also influenced the construction of bridges over the rivers Ipel and

Hron and had an equally significant impact on the lives of the local citizens, as it helped the development of trade and the expansion of markets. The railway line in question was double-tracked by 1904 and electrified by 1969 [1, 2].

Since only limited funds have been spent on repair and reconstruction works of the railway infrastructure since the period after World War II, when more than 70 % of Slovak lines were renovated, the reconstruction of the inter-station section Palárikovo - Nové Zámky was more than desirable, Fig. 1 and Fig. 2. The reason for the current reconstruction is to achieve a standard state, improve the safety and fluidity of railway transport, reduce maintenance costs and achieve a higher quality standard of passenger transport.

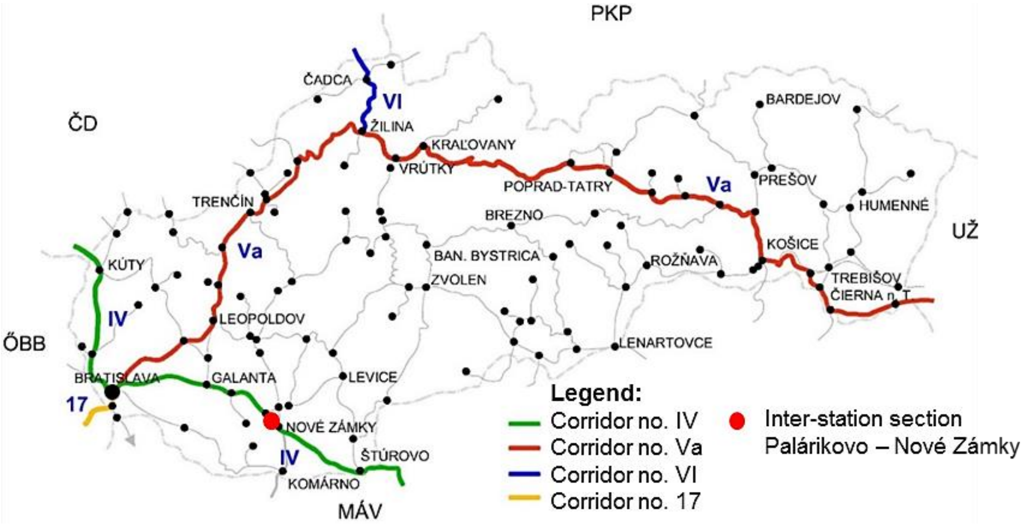

Fig. 1: Localisation of the inter-station section Palárikovo - Nové Zámky [3].

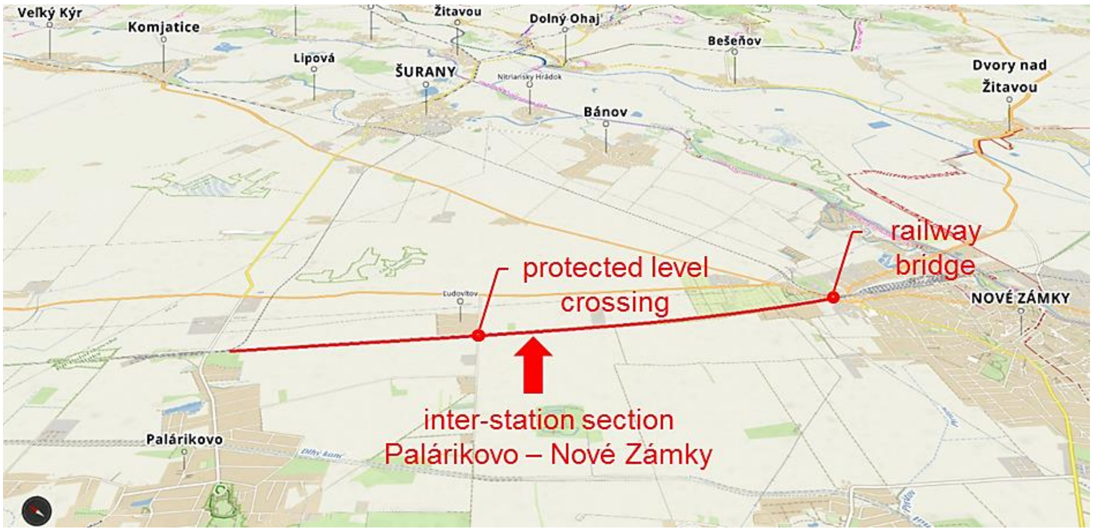

Fig. 2: Structures on the reconstructed inter-station section Palárikovo - Nové Zámky [4].

The reconstructed inter-station line section in question has a length of approx. 8 km (from km 136.124 to km 143.818 for track No. 1), while nearly the entire section has favourable alignment (smallest radius of curve R = 3800 m) and profile (slope up to 2.5 ‰). Within the reconstructed inter-station section, there is only one railway bridge structure at km 143.696 and one level crossing with a crossing angle of 90°, located on the state road connecting the villages of Ľudovítov and Štvrtky-Jur at km 139.084 194, Fig. 2, [5].

A high-quality and safe roadway, the goal of the railway line reconstruction, can only be achieved if suitable and high quality construction materials and proven technological procedures are applied. An indispensable part of the construction works is the verification of their quality – a control diagnostics. Part of this procedure (checking the deformation resistance of the structural layers of the track bed) is also one of the research activities of the Department of Railway Engineering and Track

Management (DRETM). In addition to the solution of this problem (implementation of static and dynamic load tests on the Slovak Railways infrastructure), the parallel DRETM research activity is also oriented on diagnostics, or monitoring of the track geometry [6] and monitoring of the transition zones between the earthwork and the artificial structures of the sub-ballast layers. The possibilities of simplification of the implemented control diagnostics by searching for dependence (correlation) between the values obtained by static and dynamic load tests are also currently being considered [7].

The presented article analyses the results of static load tests (static deformation modulus E_s) obtained at individual levels of the track bed in the inter-station line section Palárikovo - Nové Zámky (track No. 1), namely at the level of the subgrade surface, the sub-ballast layers (the sub-ballast upper surface) and the pre-ballasting layer (the structural layer under the sleeper).

2 Materials and methods

This part of the article will focus on the construction and material composition of the individual structural layers of the track bed applied to the track section in question. At the same time, the test method for determining the deformation resistance at the level of the individual structural parts of the track bed - the subgrade surface, the sub-ballast upper surface and the pre-ballasting upper surface will also be characterised.

2.1 Specification of the structural layers of the track bed

The structural layers of the track bed were designed on the basis of the results of the geological survey performed in 2006 according to the technical standard TNŽ 73 6312 [8]. According to the survey, the subgrade of the examined inter-station section should have contained mainly fine-grained materials, with a predominance of a sandy fraction. It was also confirmed during the reconstruction works. The evaluation of the properties of the subgrade soils was carried out in collaboration with the Department of Geotechnics, whose research activities focus, among others, on the assessment of the properties of different types of soils [9-11]. The identified soils of the subgrade surface included clay sand (SC), silty sand (SM) or sandy silt (MS).

Based on the results of the geological investigation, three types of sub-ballast layers were finally designed, designated as TPP 1, TPP 2 and TPP 3, Fig. 3, with the TPP 3 type applied at the level crossing location as part of its transition zone. The required value of the static modulus of deformation at the level of the sub-ballast upper surface was $E_s \geq 50$ MPa in almost the entire section, except at the location of application of TPP 3, where the required value was $E_s \geq 80$ MPa. The designed sub-ballast layers were further supplemented by three structures designated K1/1, K1/2 and K1/3, Fig. 4, which were applied at the transition point of the sub-ballast layers to the railway bridge structure.

Transition zones are paid increased attention in the framework of the modernisation of the Slovak Railways infrastructure. The transition zones between the sub-ballast layers objects (bridges, tunnels, underpasses, culverts, level crossings) and the earthwork are generally designed with the so-called ramp wedges with the same type of sub-ballast layers and varying structural thickness. In the case of a level crossing, the necessary stiffness gradation was addressed by a layer of cement reinforced aggregate placed on a separating geotextile and subgrade surface, Fig. 3. In the case of a single bridge structure located on this line section, the necessary stiffness gradation was solved by different compositions of the sub-ballast layers. It meant the application of various numbers and combinations of geosynthetic elements (2 or 3 reinforcing elements Tensar TX 160, with or without geosynthetic bentonite mat), Fig. 4. The required values of the static modulus of deformation at the level of the subgrade surface differed depending on the individual sections of the reconstructed inter-station section, respecting the composition of the sub-ballast layers. The required deformation resistance at the level of the sub-ballast layers was achieved by applying a combination of reinforcing geosynthetic elements (Tensar TX 160) with a crushed aggregate layer while the effort to reuse the material recovered from the track superstructure was enforced. This recovered ballast bed material was processed in a mobile crusher to a 0/45 mm fineness after the necessary verification of its environmental compatibility. This material was then applied to the sub-ballast layer of the specified design thickness and, as mentioned above, combined with the (separating and reinforcing) geosynthetics specified by the project, respecting its position in the design composition of the sub-ballast layer. The required values of the static modulus of deformation at the level of the sub-ballast upper surface were also different depending on the individual sections of the reconstructed inter-station section, with the lowest required value being $E_s \equiv E_{sub} \geq 50$ MPa or $E_s \equiv E_{sub} \geq 80$ MPa (in the zone of the level crossing). At the level of the pre-ballasting layer, the required value of the static modulus of deformation was $E_s \equiv E_{bb} \geq 80$ MPa [5].

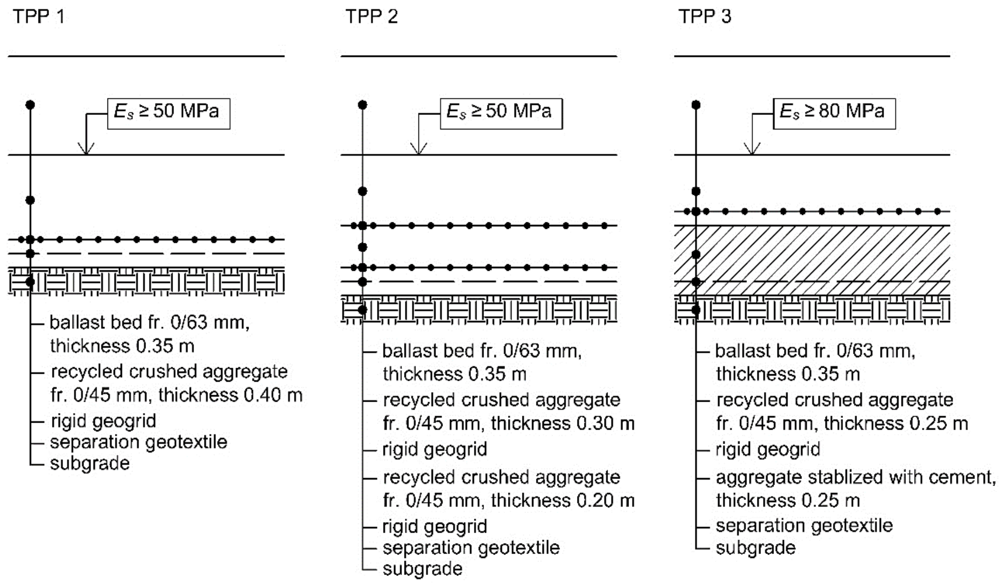

Fig. 3: Types of track bed applied within the reconstruction of the inter-station section Palárikovo - Nové Zámky.

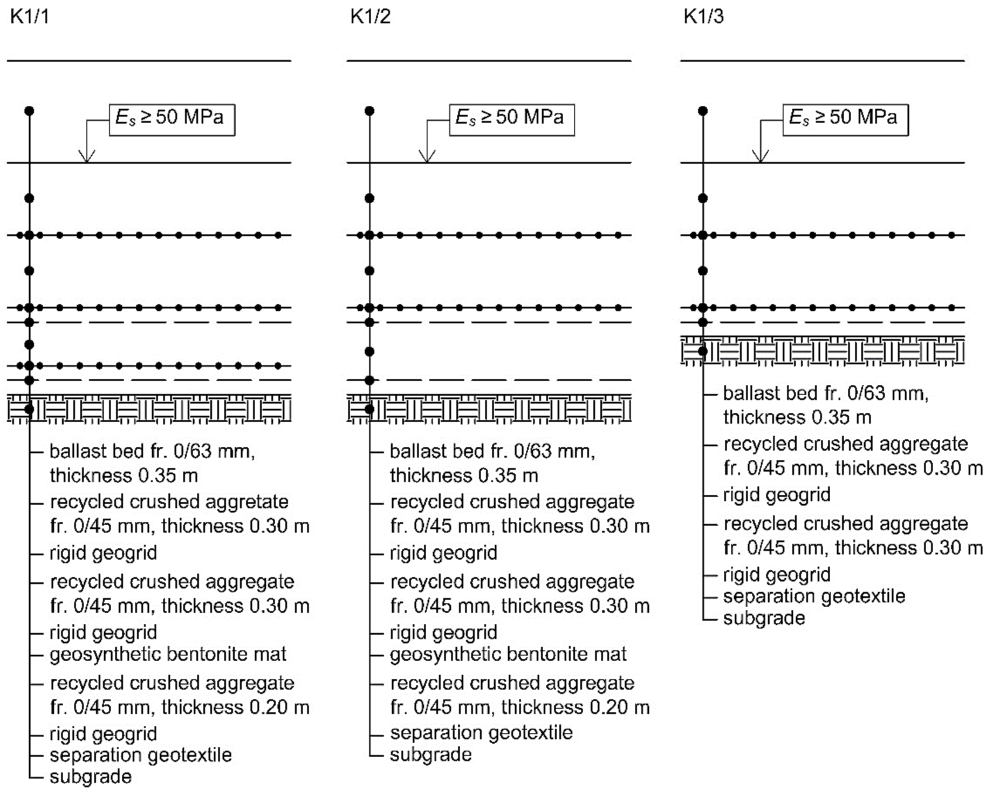

Fig. 4: Transition track bed structures applied in the transition zones of the railway bridge.

2.2 Methodology of determining the deformation resistance of the structural layers of the track bed

The initial diagnostics of the track bed relies on detecting the deformation properties of individual structural parts of the track bed (the subgrade surface, the sub-ballast upper surface and the pre-ballasting layer). The results of the diagnostics serve for assessing the current state of the structural composition and the deformation resistance of the individual structural parts (layers) of the track bed in the framework of not only preparatory work but also repair, rehabilitation, reconstruction or modernisation activities on the railway line in the area of the sub-ballast layers.

Within the track bed structure diagnostics, the determined or controlled deformation parameters are the static or dynamic modulus of deformation of the structural parts of the track bed mentioned above and the degree of compaction (an additional parameter obtained from the implementation of a static load test). The static modulus of deformation of the structural layer can be determined in the case of a standard construction of the railway superstructure (gravel ballast bed) according to the methodology specified in the regulation TS4 Railway substructure - Appendix 6, [12]. In the case of a non-standard construction of the railway superstructure (gravel-free railway superstructure, so-called slab track), the static load test is carried out using the methodology specified in DIN 18 134 [13], which was also adopted by the German Railways - DB A.G. Although the resulting parameter of static load tests using both of the above-mentioned methodologies is the static modulus of deformation, its different values are achieved for identical boundary conditions of measurement (measurement of the same structural layer). The values of the static modulus of deformation, determined differently, result from the very different fundamentals of the measurement methodologies. Specifically, a differing value of the pressure acting on the load plate is applied, a different method is used for recording the settlement of the load plate in individual load stages, and the calculation of the static modulus of deformation uses different relationships).

Following [12], the static modulus of deformation E_s is calculated according to the relation

$$E_s = \frac{1.5 \cdot p \cdot r}{y} \text{ [MPa]}, \tag{1}$$

where:
p - specific pressure acting on the plate [MPa],
r - load plate radius, [m],
y - total average loading of the load plate in the second cycle [m].

Following [13], the static modulus of deformation E_{def} is calculated according to the relation

$$E_{def} = 1.5 \cdot r \cdot \frac{1}{a_1 + a_2 \cdot \sigma_{0,max}} \text{ [MPa]}, \tag{2}$$

where:
r - load plate radius, [m],
a_1 - constants of the second-degree polynomial, [MN/m^2],
a_2 - constants of the second-degree polynomial, [MN^2/m^4],
$\sigma_{0,max}$ - max. average normal stress below the loading plate in first loading cycle [MN/m^2].

Determining the deformation resistance of the structural layer using a dynamic impact load test as part of the initial diagnosis of the track bed can only be carried out in justified cases (hard-to-access places) and when a structural layer built from non-cohesive soils is to be diagnosed.

The DRETM team members have currently been engaged in research activities focused on comparing the results of the deformation resistance of the structural layers of the track bed determined by static and dynamic load tests using the ŽSR and the DB A.G. methodology. Their results will be published shortly. The simultaneously created database of results will assess the relevance of the design values of deformation resistance for individual structural parts of the track bed for the anticipated amendment of the regulation [12].

The diagnostics of the deformation resistance of the structural layers of the track bed were carried out in the inter-station section Palárikovo - Nové Zámky following the ŽSR methodology presented in [12] for the standard construction of the railway superstructure by a static load assembly, Fig. 5.

The assessment of the quality of the construction work in the inter-station section in question was carried out at three construction levels, namely at the level of the subgrade surface, the sub-ballast upper surface (on a layer of crushed aggregate fr. 0/45 mm) and the pre-ballasting layer (on a layer of ballast material fr. 31.5/63 mm). The measurements were carried out in two loading cycles when a rigid circular load plate with a diameter of 300 mm was successively (by specified loading stages of 0.050 and 0.10 MPa) pushed up to a maximum contact stress of 0.20 MPa (on the subgrade surface, sub-ballast upper surface) or 0.40 MPa (on the pre-ballasting layer). The output of the measurement was the indirectly determined value of the static modulus of deformation E_s of the structural layer of the track bed using the relation (1) and the quality of compaction characterised by the ratio E_{s2}/E_{s1} [14]. The ratio of the value of the static modulus of deformation obtained in the second and the first measurement cycle expresses the degree (quality) of compaction of the tested structural layer.

Fig. 5: Implementation of the static load test at the level of the sub-ballast upper surface in the area of the Ľudovítov stop and level crossing.

3 Results and discussion

Static load tests on the reconstructed inter-station section Palárikovo - Nové Zámky were implemented from September 2022 to December 2022. The measurements were carried out on the entire reconstructed section in a length step of 200 m while the measurements at the level of the pre-ballasting layer were shifted by 50 m compared to the measurements at the level of the subgrade surface and the sub-ballast upper surface. In this way, a comprehensive overview of the quality of the construction works carried out on the inter-station section in the entire profile of the track bed was ensured. A summary of the measured values of the static modulus of deformation of the individual structural layers of the track bed for Track 1 is presented in Fig. 6.

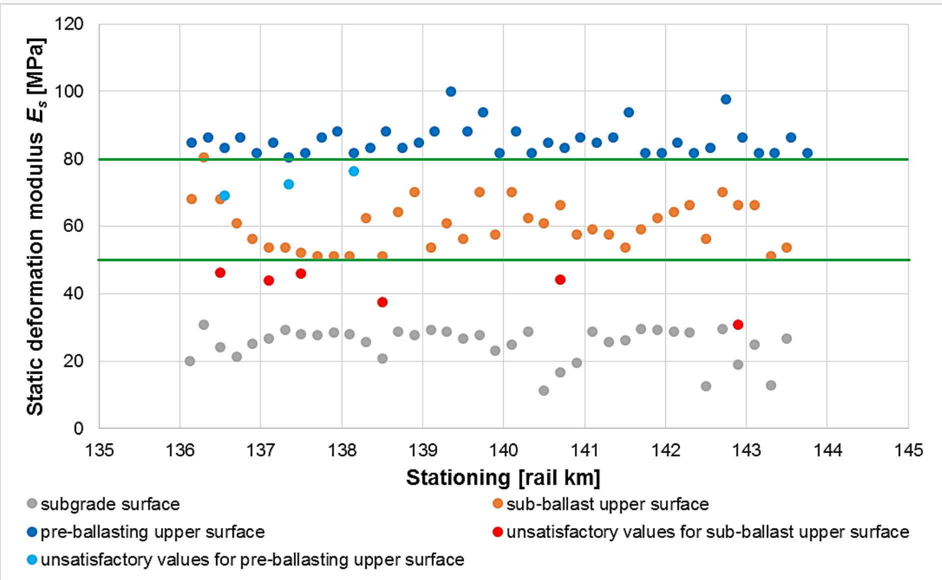

Fig. 6: Summary of the measured values of the static modulus of deformation on the surface of the individual structural layers of the track bed (subgrade surface, sub-ballast upper surface, pre-ballasting upper surface) for track No. 1 in the reconstructed inter-station section Palárikovo - Nové Zámky.

Fig. 6 indicates that all the values of the static modulus of deformation determined at the level of the subgrade surface (grey circles) reached values of more than 10 MPa. However, in the preparation of the subgrade surface, the construction company used only smooth compaction, and the excavation of the overlaying layers was sectional to avoid possible long-term exposure to adverse climatic influences (especially rainfall). In the case of the subgrade surface of sandy silts, it was possible to achieve values of up to 80 MPa in the dry season immediately after excavation and only smooth compaction. (The initial measurements were later repeated after exposure to rainfall). The compaction by vibration, dynamic effects of traffic and excessive rainfall significantly affected the decrease in the deformation resistance of the subgrade surface consisting of the respective subgrade soils. The lowest values of the static modulus of deformation at the level of the subgrade surface demonstrated in Fig. 6 were determined immediately after the heavy rainfall. The orange and red circles in Figure 6 present the values of the static modulus of deformation determined at the sub-ballast upper surface. The orange circles characterise the unsatisfactory values, which in all cases were caused by granulometrically unsuitable material (crushed aggregate fr. 0/45 mm) applied at the beginning of the reconstruction – in the first part of the reconstructed section. The first four cases of unsatisfactory values of the static modulus of deformation were caused by the absence of an aggregate sorting machine. Here, the recycled aggregate from the ballast bed was only crushed in a crusher and did not pass through the sieve system, containing a higher amount of fine fraction. The other two cases of unsatisfactory deformation resistance values were also due to the unsuitable material - crushed aggregate of fr. 0/45 mm, which also contained a higher amount of fine fraction. In the problematic areas, it was replaced with a material of suitable grain size and the required deformation resistance value was subsequently achieved without any problems at the level of the sub-ballast upper surface. The light and dark blue circles represent the values of the static modulus of deformation determined at the level of the pre-ballasting layer. The light blue circles characterise unsatisfactory values caused by the application of insufficient compaction. After further compaction and re-measurement, the required values of the deformation resistance of the pre-ballasting layer were achieved.

The degree (quality) of compaction at the level of the subgrade surface was determined to be between 1.27 and 2.50, at the level of the sub-ballast upper surface between 1.16 and 2.37 and the level of the pre-ballasting layer between 1.30 and 2.48. The required value of the compaction rate (quality) was satisfactory in all cases, since for coarse-grained materials according to [14] $E_{def2}/E_{def1} \leq 2.60$ and for fine-grained materials $E_{def2}/E_{def1} \leq 2.50$.

4 Conclusions

The railway line Bratislava - Štúrovo, including the reconstructed inter-station section Palárikovo - Nové Zámky, is one of the oldest railway lines in Slovakia. As this line is part of the Pan-European Corridor IV, connecting Dresden, Germany, with Arad, Romania, it is necessary to increase its quality, safety level and interoperability capability.

The article authors assume that the knowledge and experience gained during the reconstruction of the inter-station section Palárikovo - Nové Zámky will be applicable in the reconstruction of track No. 2 of this inter-station section, but also of the following line sections of the corridor running through the territory of the Slovak Republic. The following conclusions can be drawn so far:

1) The subsoil of the railway line consisting of clay sand, silty sand and sandy silt is highly resistant to deformation after excavation in the dry season due to its compactness (it is possible to measure a static modulus of deformation of up to 80 MPa). The vibration, excessive dynamic effects of construction machinery, and adverse climatic conditions (especially excessive rainfall) cause a significant decrease in the deformation resistance of these soils. It is, therefore, advisable to compact the material only smoothly after excavation and to carry out the excavation in sections while constructing the overlaying layer as soon as possible (it is necessary to eliminate the effects of excessive precipitation). It is desirable to have surface water drainage constructed or resolved in advance.

2) By applying a combination of tri-axial reinforcing geosynthetic elements Tensar TX 160 and recycled crushed aggregate fr. 0/45 mm of sufficient thickness in the structural composition of the sub-ballast layers, it is possible to achieve the required value of the static modulus of deformation at the level of the sub-ballast upper surface $E_s \geq 50$ MPa (the minimum values of the static modulus of deformation on the subgrade surface were about 10 MPa). However, it is necessary to consider the possible excessive fine fraction in the crushed aggregate (in addition to the crusher, a sorting machine is also vital for the aggregate recycling process).

3) In the case of the assessment of the deformation resistance at the level of the pre-ballasting layer, the main success factors (achieving the required values of deformation resistance) are the quality of the aggregate used (ballast material) and the necessary compaction work applied. The ballast bed aggregate must be compacted sufficiently (it must not be degraded by crushing) and time

must be allowed for it to consolidate. Ideally, a compaction trial should be carried out at the start of the work to determine the optimum compaction work (number of passes or compaction intensity).

The content of the article is related to the papers concerning the control diagnostics carried out on the upgraded sections of the Pan-European Corridor Va [15, 16].

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